



BioSentinel/Mars: Interplanetary Space Radiation BioSensor Experiment in Transit on Mars 2020

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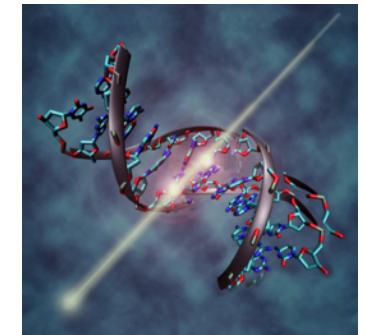
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BioSentinel/SLS EM-1 Project Objectives

Advance Exploration System (AES) Program Office selected BioSentinel to fly on Space Launch System (SLS) Exploration Mission (EM-1) as a secondary payload

- Payload selected to help fill HEOMD **Strategic Knowledge Gaps in Radiation effects on Biology**
- Development Schedule based on December 2017 Launch
- **Key BioSentinel Project Objectives**
 - Develop a *deep space nanosat* capability
 - Develop a *radiation biosensor* useful for other missions
 - Define / validate **SLS secondary payload interfaces**
 - Compare life science results across **multiple space environments** relevant to human exploration
- **BioSentinel/Mars 2020 Objectives & Implementation**
 - Measure radiation effects on biology over a 9-month Earth-to-Mars voyage
 - Provide life science results across **multiple space environments**
 - Fly on cruise stage using power and data resources; mission ends on approach to Mars





BioSentinel Relevance to SKGs

GOALS

- Life science studies beyond low Earth orbit (LEO) relevant to human exploration
- Simple organisms can inform on greatest risks to humans beyond LEO:
 - ***validate models, improve protection strategies, mitigate dangers***
- Critical advances to autonomous life support technologies for small organisms

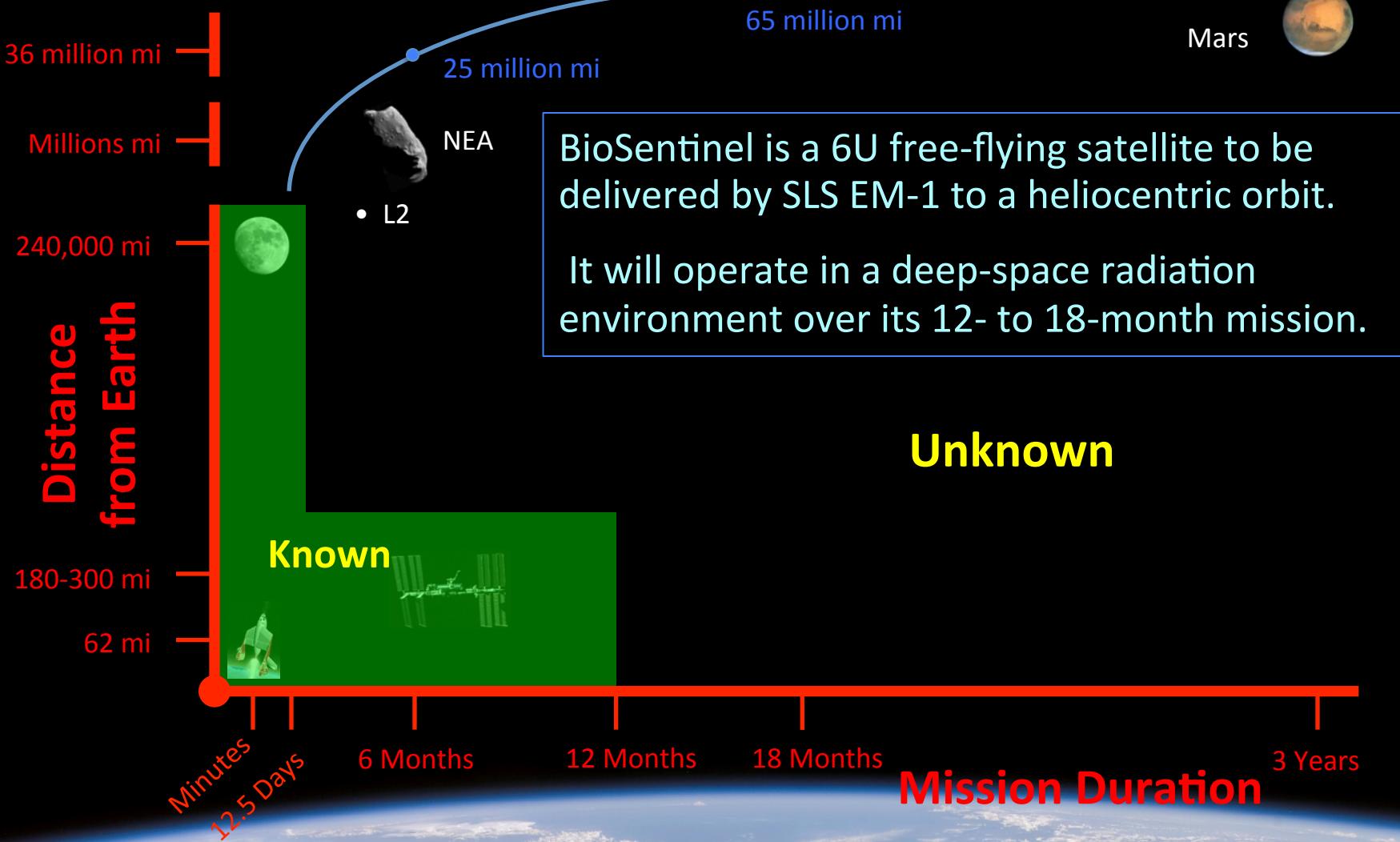
Filling Strategic Knowledge Gaps (SKGs)

SKG documents	Gaps
Mars Precursor Strategic Analysis Group (P-SAG) SKGs, May 2012	II-D Effects of radiation and effectively low g on biology and physiology III-G Radiation shielding, specifically for subsystems
P-SAG & MEPAG (Mars Exploration Program Analysis Group)	B3-2, Crew Health and Performance: place detector in orbit to measure energy spectra during Solar Energetic Particle Events (SPEs)
SBAG SKGs, Nov 2012	III-B: Ionizing Radiation Environment at Small Body Surfaces
LEAG-SAT SKGs, March 2012	A4-4: Auto systems tech demo A4-6: Life support tech demo A4-7: Mechanisms tech demo B3-6: Radiation shielding B5-3: Microbial survival, Mars conditions

The 1st Biology Experiment beyond LEO since Apollo

The limits of life in space, as we know it, is 12.5 days on a lunar round trip or 1 year in LEO. As we send people further into space, we can use model organisms to understand the biological risks and how they can be addressed.

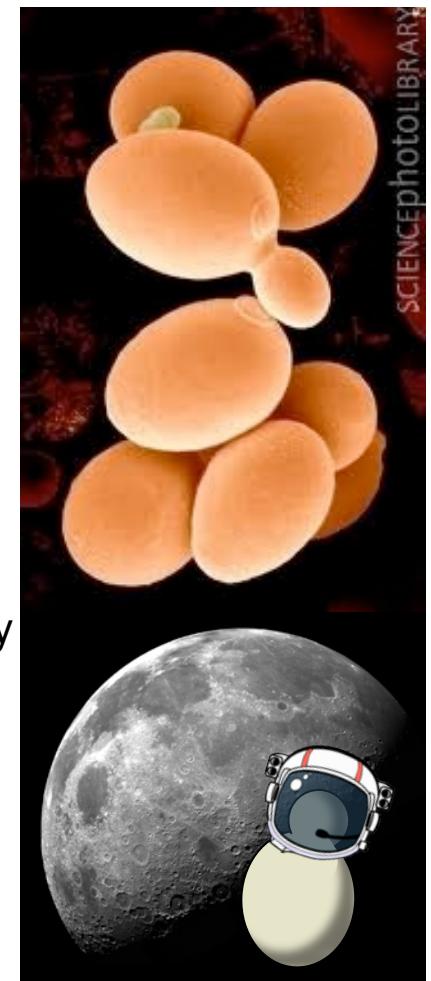
Beyond





BioSentinel Science Concept

- **Quantify DNA damage from space radiation environment**
 - Space environment cannot be reproduced on earth
 - Omnidirectional, continuous, low flux with varying particle types
 - Health risk for humans spending long durations beyond LEO
 - Radiation flux can spike 1000x during a solar particle event
- **Correlate biologic response with LET and TID data**
 - BioSensor payload uses engineered *S. cerevisiae* (yeast)
 - Measures rate of Double Strand Breaks (DSB) in DNA
 - Linear Energy Transfer (LET) spectrometer measures & bins particle LET and count
 - Total Ionizing Dose (TID) sensor measures integrated deposited energy
- **Yeast assay: microfluidic arrays monitor DSB/repair**
 - Three strains of *S. cerevisiae*, two controls and engineered strain
 - Wet and activate multiple banks of microwells over mission lifetime
 - DSB and associated repair enable cell growth and division
 - Activate reserve wells in event of a Solar Particle Event (SPE)

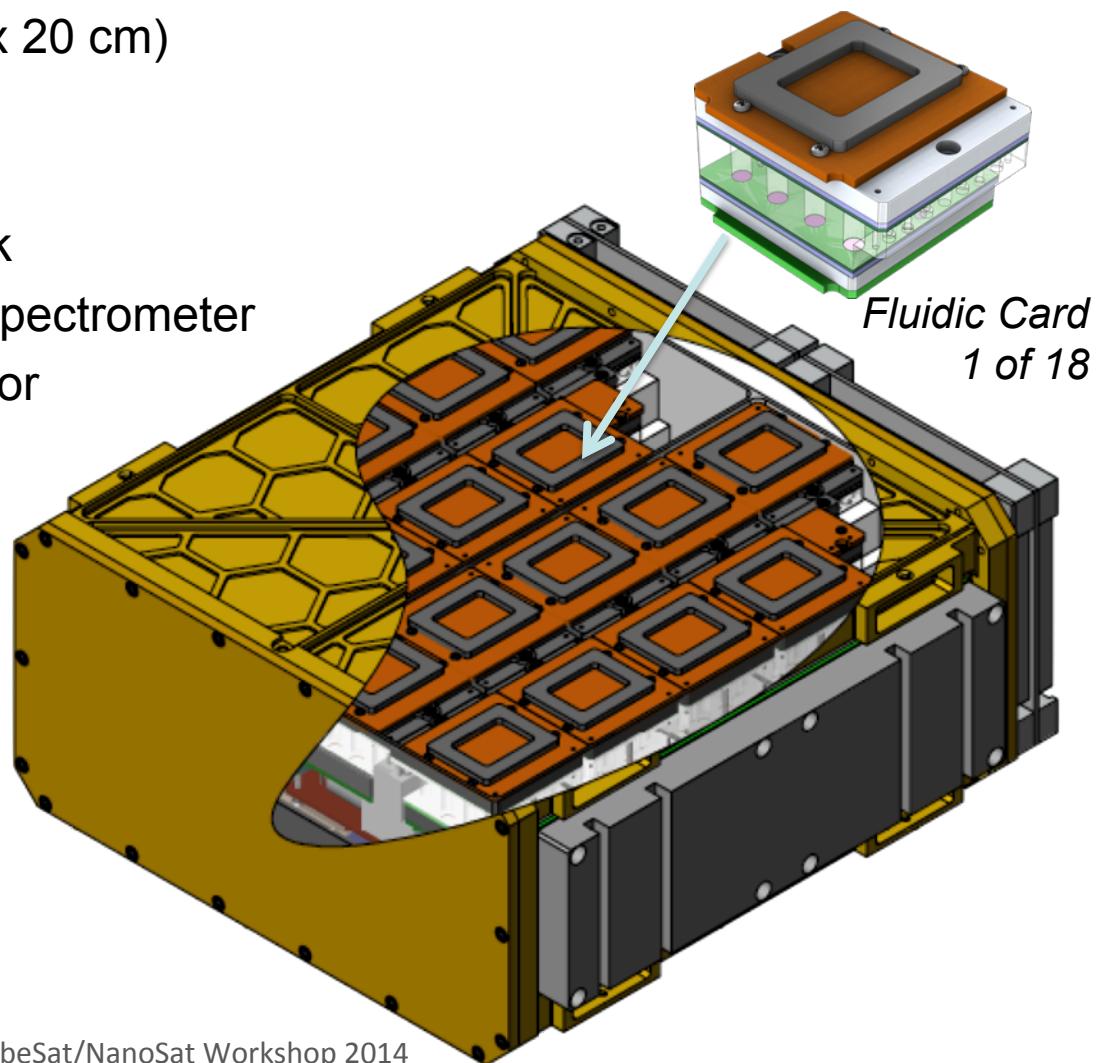




BioSentinel/Mars Instrument

Use the BioSentinel Payload currently in development for EM-1

- 18-fluidic card BioSensor Payload; each has 16 microfluidic wells for yeast
- Volume: ~4U (10 cm x 20 cm x 20 cm)
- Mass: 6 – 8 kg
- Power: 5 – 8 W
- Data Volume: 0.2 – 1 MB/week
- Linear energy transfer (LET) Spectrometer
- Total ionizing dose (TID) Sensor
- Attach to Mars 2020 Cruise Stage for power and data relay data to Earth
- Wet 1 card every ~ 2 weeks over the 9-month Cruise Phase
- Record consequences of cosmic radiation including solar particle event(s) if they occur

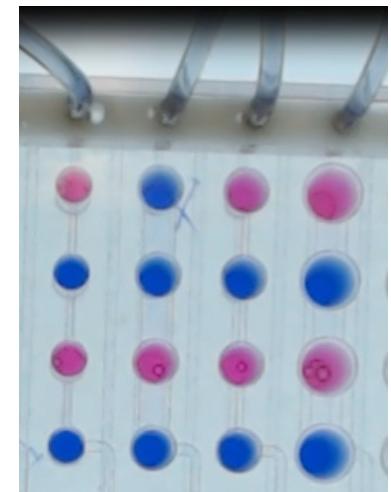




BioSentinel/Mars Instrument

Biological Support & Measurement Systems

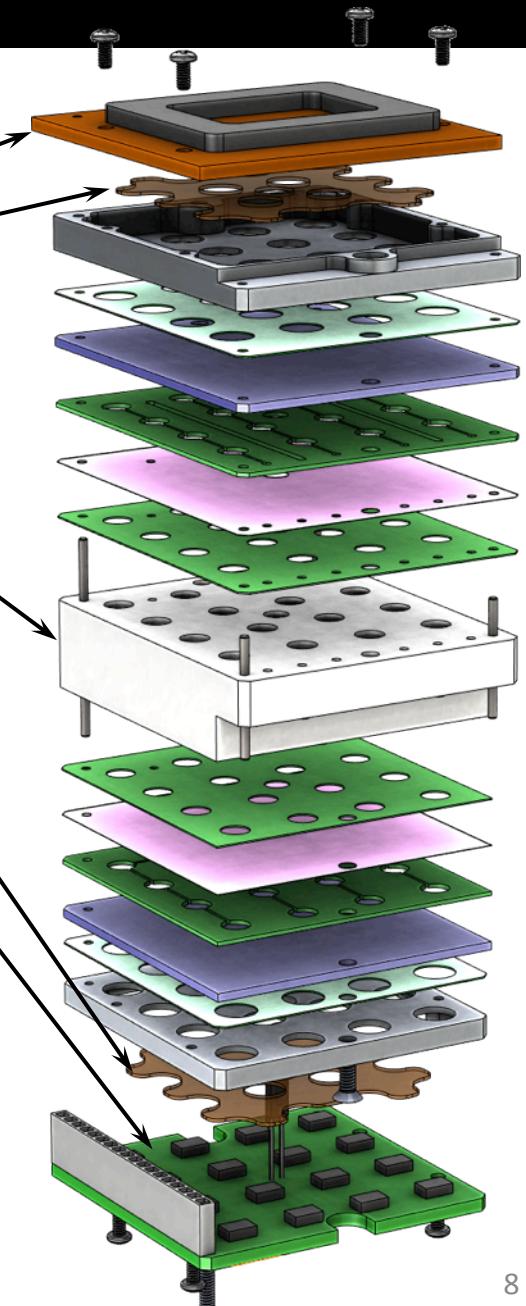
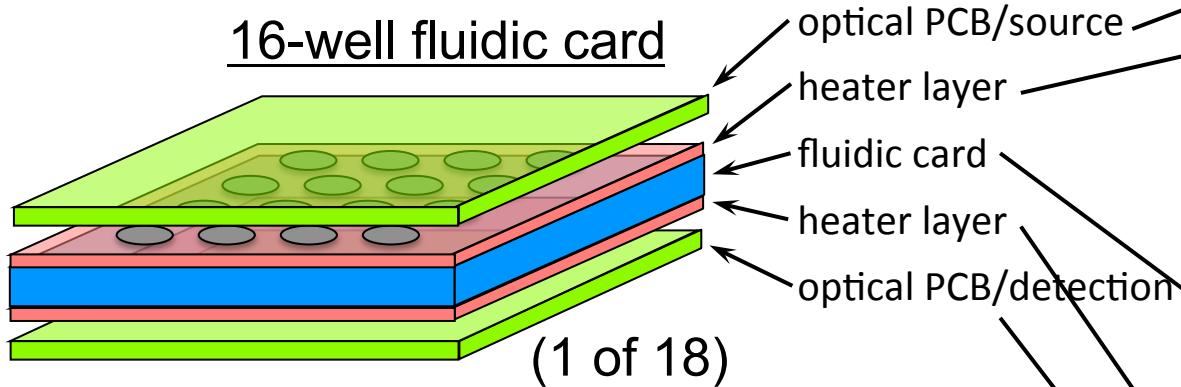
- support biology in stasis & growth
- enable & perform measurements
- compatible with multiple platforms
 - robust, standard data & power interfaces
 - free flyer (EM-1), Mars 2020, ISS, ground experiments
- Configuration: 4U hermetic containment vessel
 - 1 atm internal pressure, low RH
 - **Fluidics:** 18 sets (cards) of 16 µwells each
 - ❖ 2 cards / month; 1 – 2 sets on “SPE standby”
 - **Pumps, Valves, Tubing, Media** external to cards
 - ❖ low-permeability materials to keep dry yeast dry





BioSentinel/Mars Instrument

Payload Configuration (cont'd.)



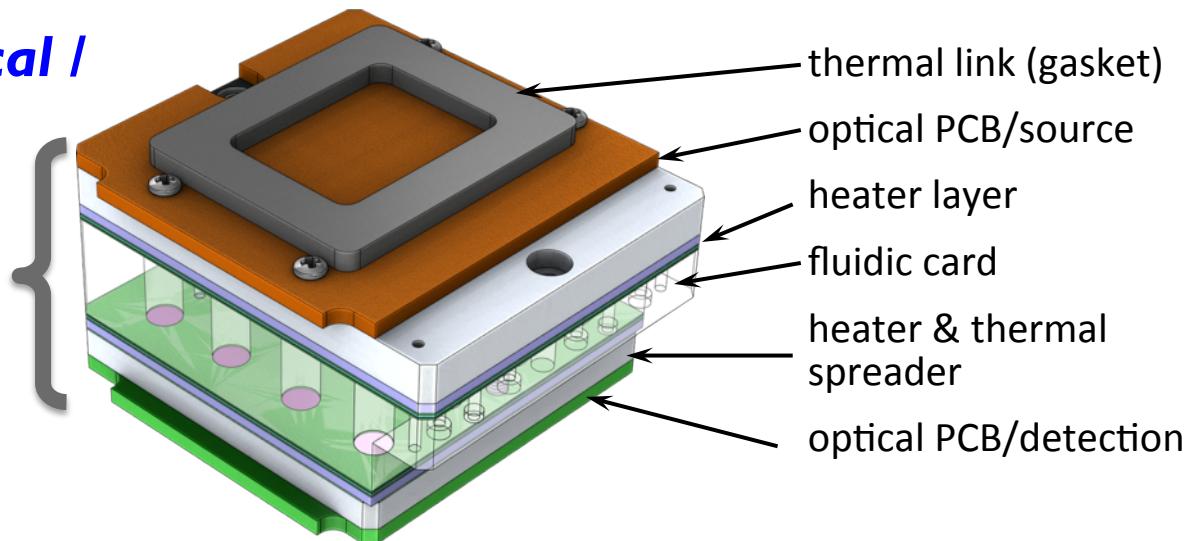
- **Optical absorbance measurement per well**
 - Dedicated 3-color optical system at each well
 - Measure dye absorbance & optical density (cell population)
 - Ground pre-calibration + in-flight “active” cal.
- **Pressure & humidity sensors** in P/L volume
- **Dedicated thermal control system per card**
 - 23°C with 1 °C uniformity, accuracy, stability
 - 1 temp. sensor per card: closed-loop control



BioSentinel/Mars Instrument

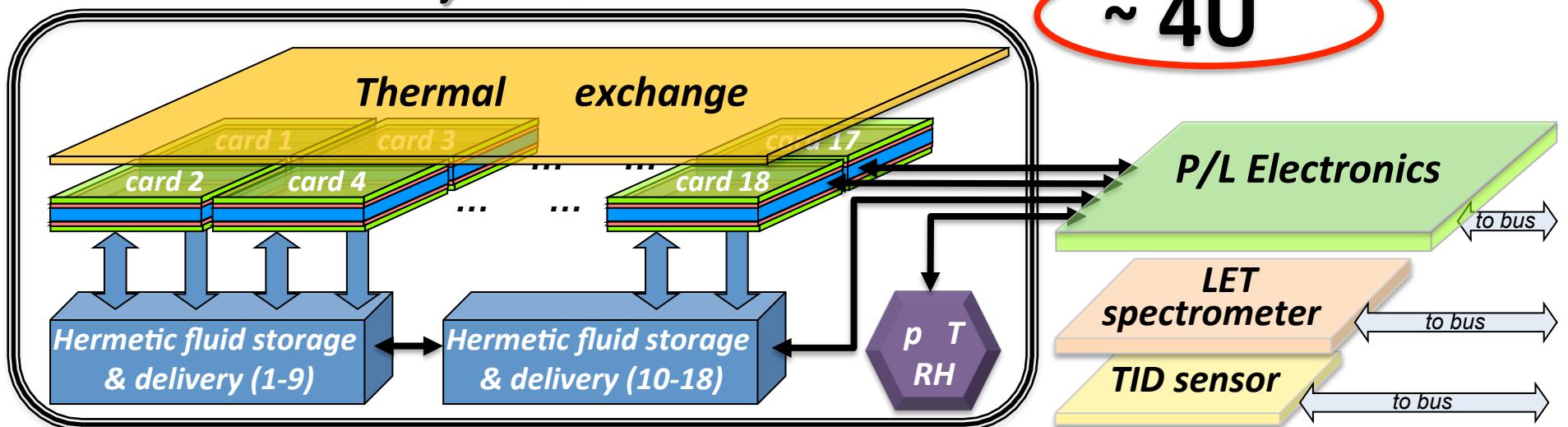
Biology / fluidics / optical / thermal configuration

**16-well card
= 1 “set”
(18 sets total)**



1 atm Payload Containment

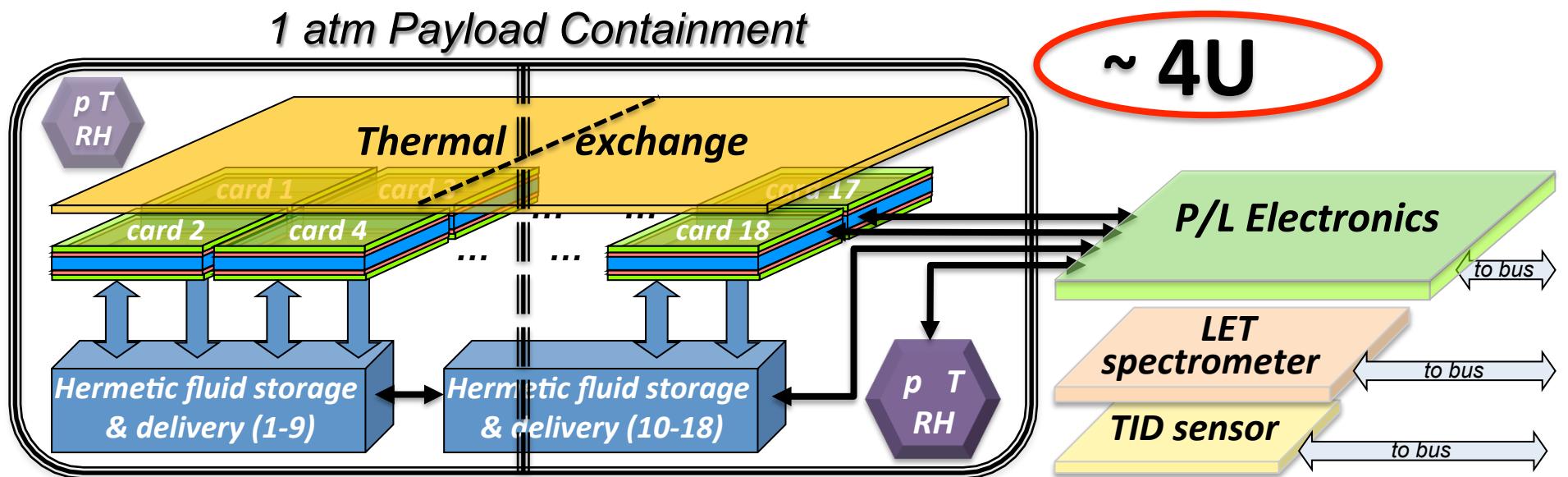
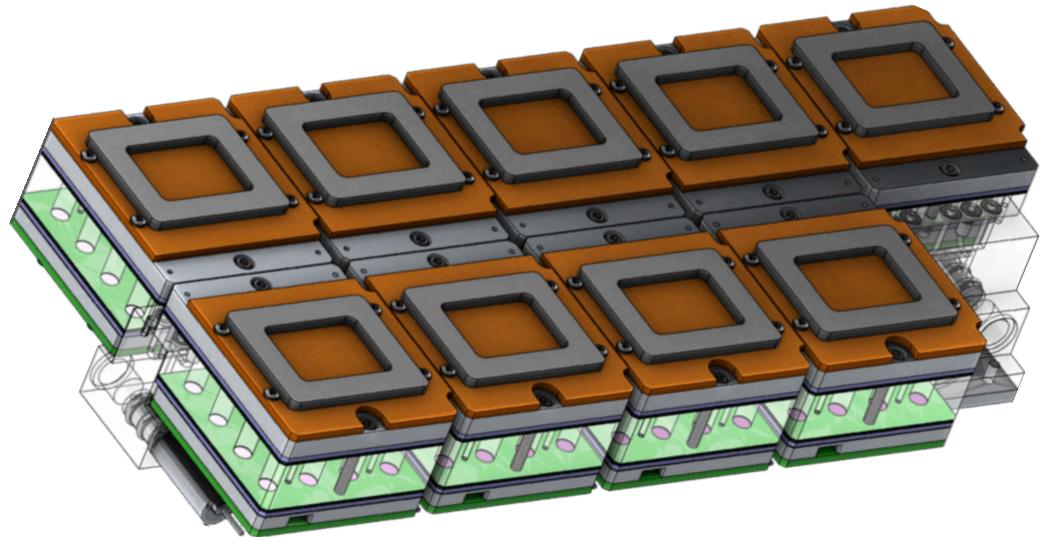
$\sim 4U$





BioSentinel/Mars Instrument

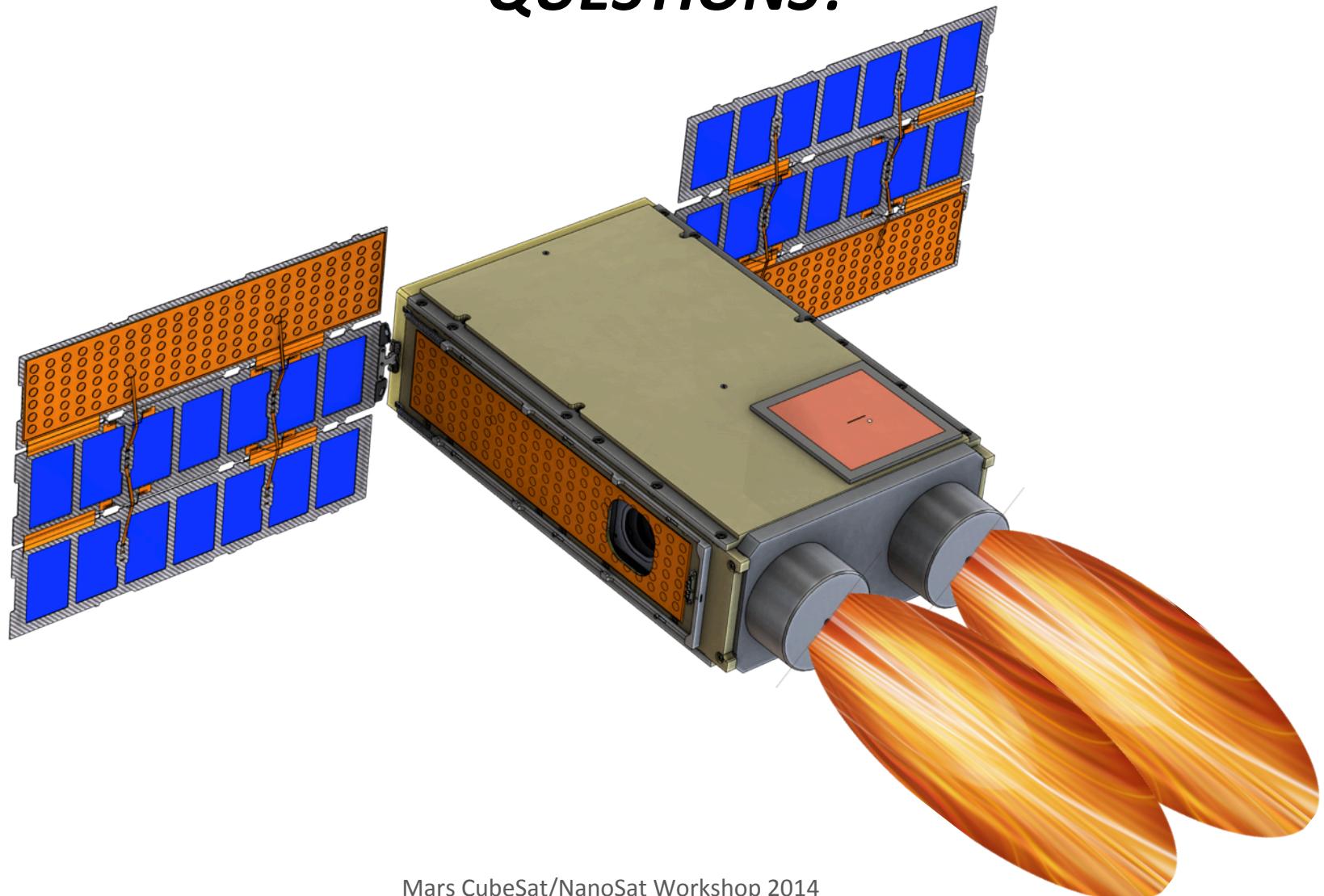
Biology / fluidics / optical / thermal configuration





BioSentinel/Mars Instrument

QUESTIONS?

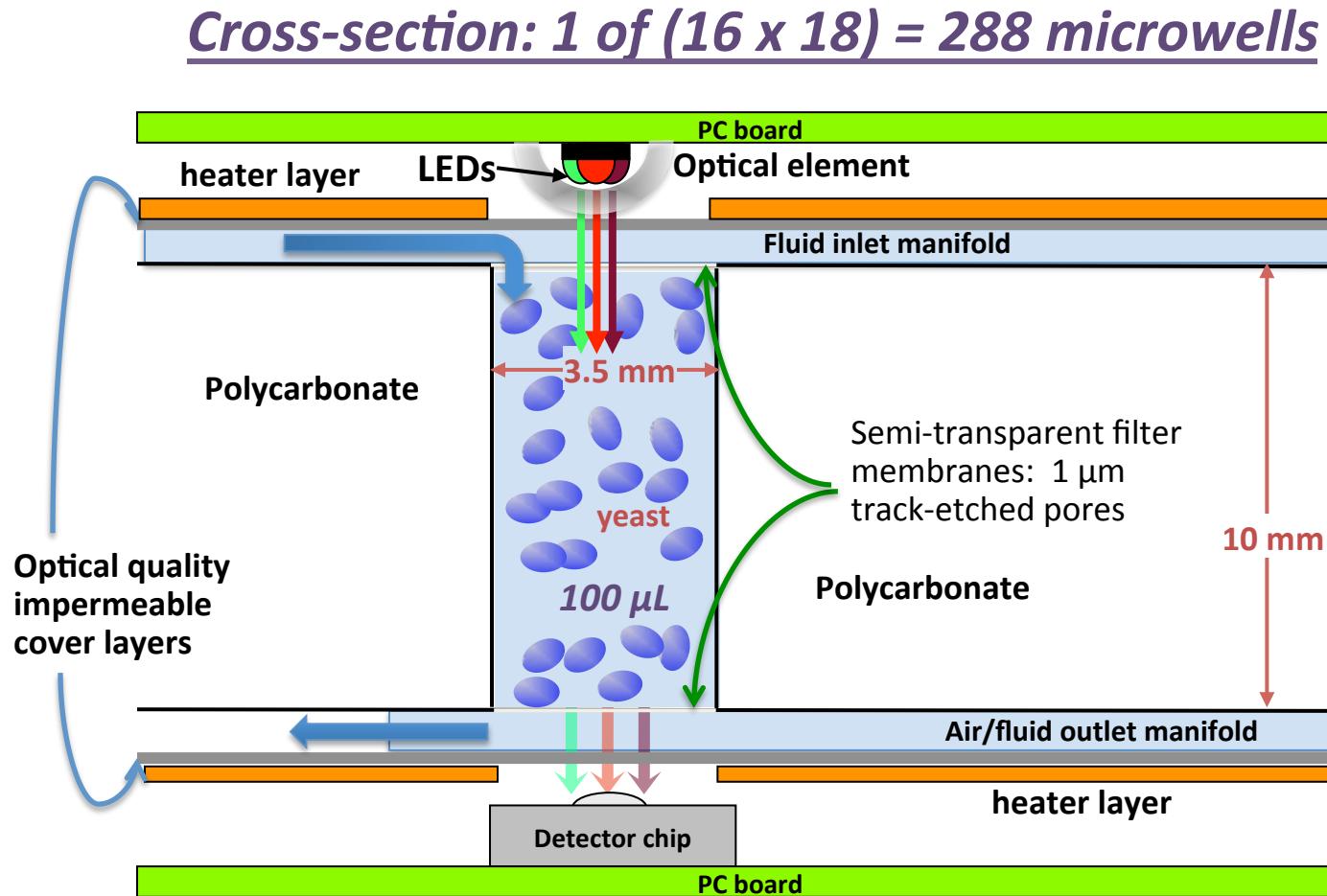


Mars CubeSat/NanoSat Workshop 2014



BioSentinel/Mars Instrument

Payload: Biology / Fluidic / Optical / Thermal Configuration



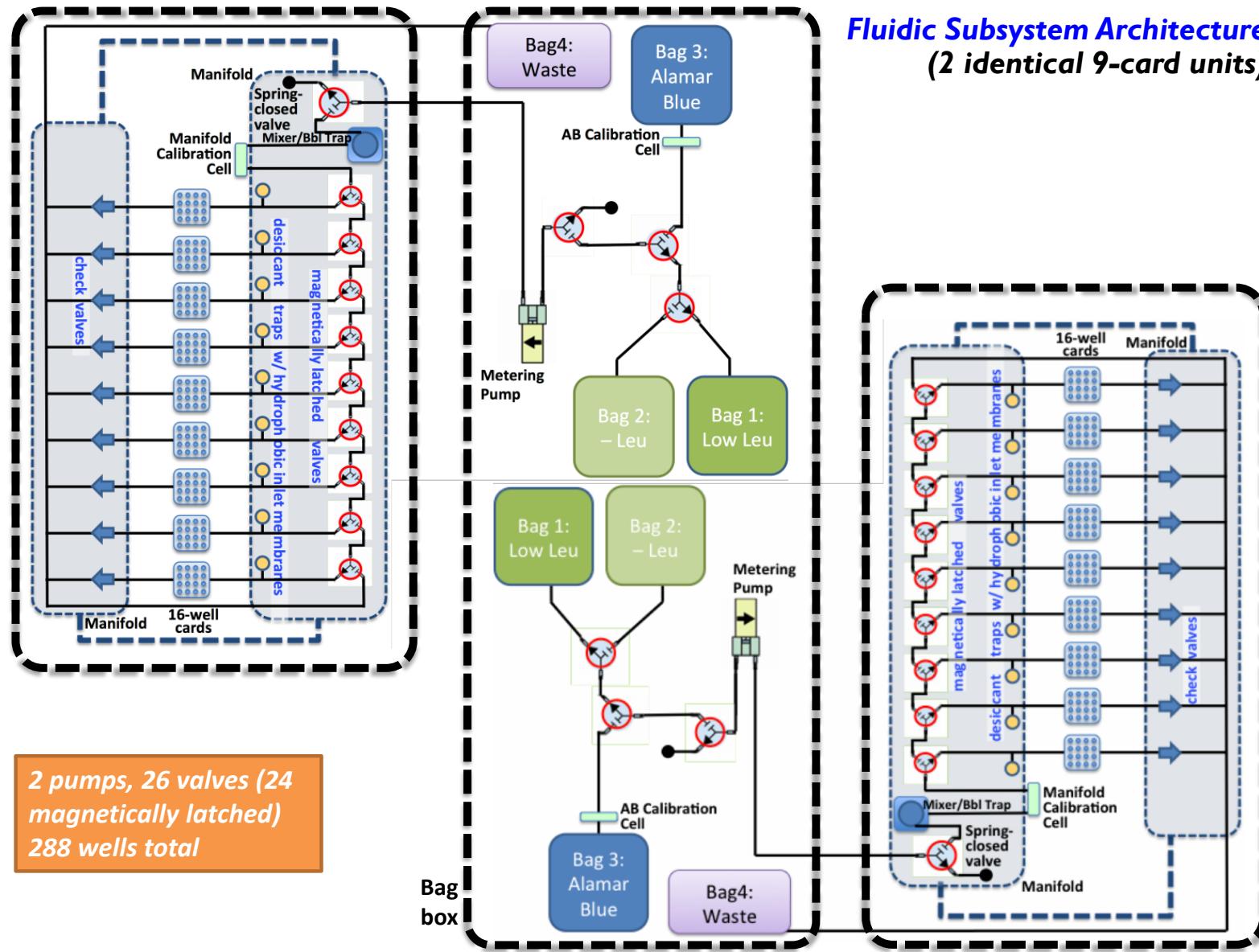
Yeast dried onto
μwell walls prior
to integration &
launch

1 set of 16
μwells wetted
out monthly

3 LEDs (570, 630,
850 nm) and
detector, per
well, track
growth *via*
optical density
and cell
metabolic
activity *via* dye
color change



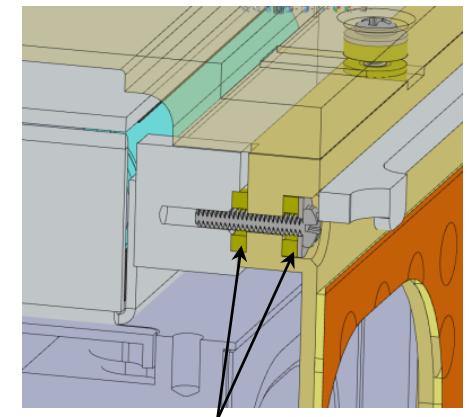
BioSentinel/Mars Instrument



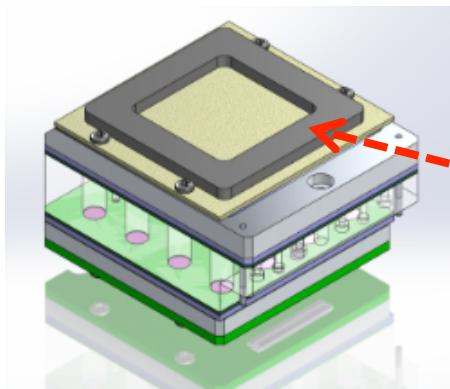


Payload Configuration: Thermal Requirements & Design

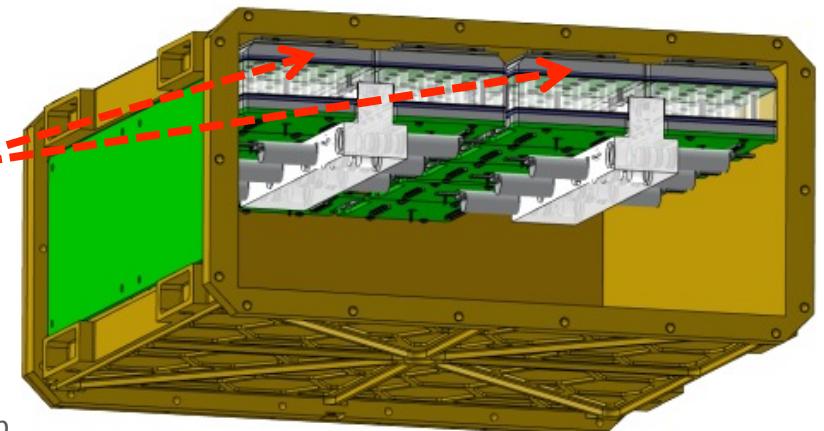
- **23 °C biology temp.** for “active growth” fluidic card
- **~4 °C for non-active cards:** maintain biological viability
 - “Keep-alive” 4 °C minimum at all times, cards & reagents
- Minimize temp. gradients in active fluidics card
- Minimize power to heat fluidics during experiment
- Minimize heat flow to surrounding non-active cards
- Kapton heaters + spreader bonded to each card
- **Challenge:** no active control from L-6 mo to deployment



Isolating washers/spacers (Ultem, SS, Al, etc.): tunable thermal interfaces enable structural design before complete thermal details



GapPad: tuned thermal path to payload enclosure by choice of pad dimensions



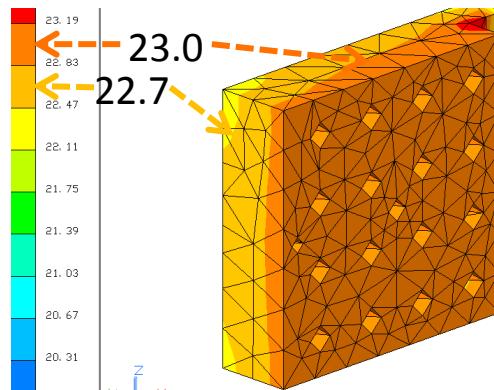
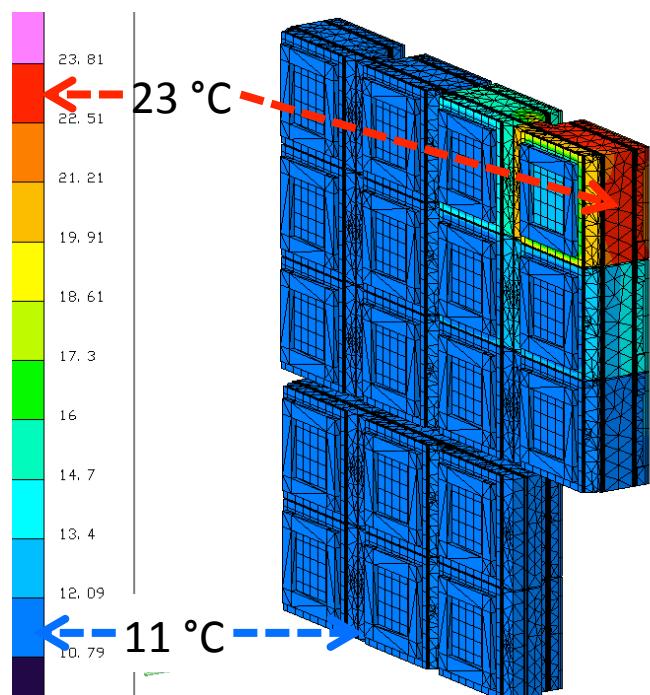
1 of 18 fluidic cards

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Payload Configuration: Thermal Model Results

**As-modeled, < 0.5 W
to heat single card**



- 46,000 Nodes, 6 heat loads, 18 heaters, 206 contactors; FD & FE objects
- Fluidics card components meshed separately (2200 nodes) at high res.: capture thermal gradients, uniformity





Payload Configuration: Electronics & Components

- **3 Payload Systems: Biosensor, LET spectrometer, TID**
 - Minimize electronics inside hermetic biosensor container
 - Earlier delivery of “in-can” electronics to bio team to start long-term tests
 - Less hardware tied up in long-duration tests
 - Changes less likely within biocompatibility zone
- **Subsystem Components**
 - Optical: 3 discrete LEDs – 0402 SMD pkg, “Y” geometry
 - TAOS intensity-to-freq. detector: 5-6 logs linear dynamic range
 - Thermal: AD590 sensors: easy integration; Kapton flex ckt. heaters
 - Humidity: Sensirion SHT15
 - Pressure: Motorola MPL3115A2
 - TID: Teledyne uDOS001 + charge pump + MSP430 + RS422
 - LET spectrometer: provided by RadWorks team



Payload Configuration: Processor, Interface, Power, Rad.

- **Control and storage provided by bus processor**
 - Implemented as a cFE task
- **Payload Local Processor: baseline MSP430**
 - FRAM, high radiation tolerance
- **Comm. Interface to Bus / Host: RS-422**
 - Simple, robust
 - Serial is standard, easier ground testing
 - RS-485 enhancement (S/W only) for greater functionality
- **Comm. Packet Protocol**
 - CCSDS: standard
- **Power: 5 VDC & unreg (9-28 VDC); multiple ground returns**
- **Rad-hard electronics: Power parts, regulation and switches**
 - Cannot afford power, space, cost for full rad-hard design
 - Total dose inside is low-moderate; spot shielding feasible

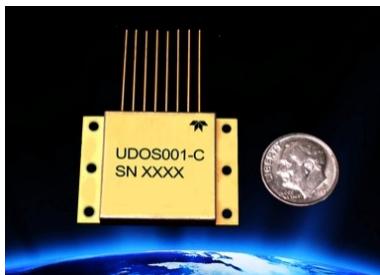


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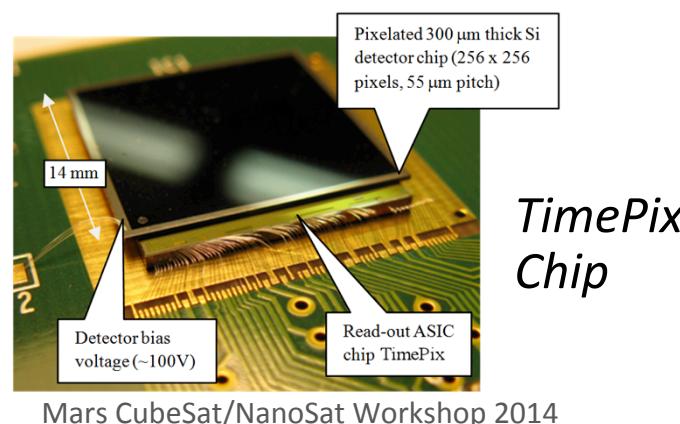
Payload Configuration (cont'd.)

• Radiation Sensors

- LET “spectrometer” device: TimePix family solid-state device
 - measures coarse linear energy transfer spectra
 - Operates in time-over-threshold (TOT) mode as Wilkinson-type ADC
 - ❖ *direct energy measurement per pixel*
 - frequent measurement/caching of results; downlink binned LET spectra
 - provide “local space weather” periodic (~ hourly) snapshot
- Total integrating dosimeter (TID): Teledyne μDOS001
 - ranged analog outputs (low, med, high, log)
 - 15 μrad res. (~20 s ambient GCR)



Teledyne
dosimeter

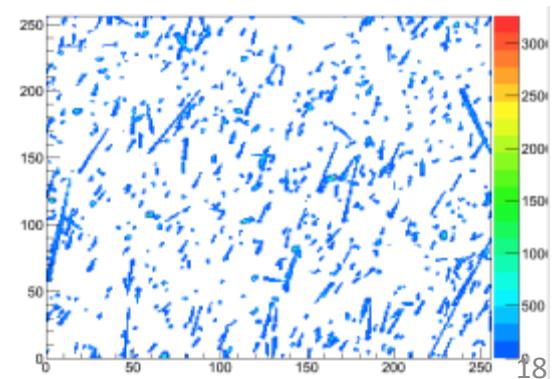


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Typical TimePix frame:
256 x 256 x 14 bits

0.25 – 150 keV/ μm LET range

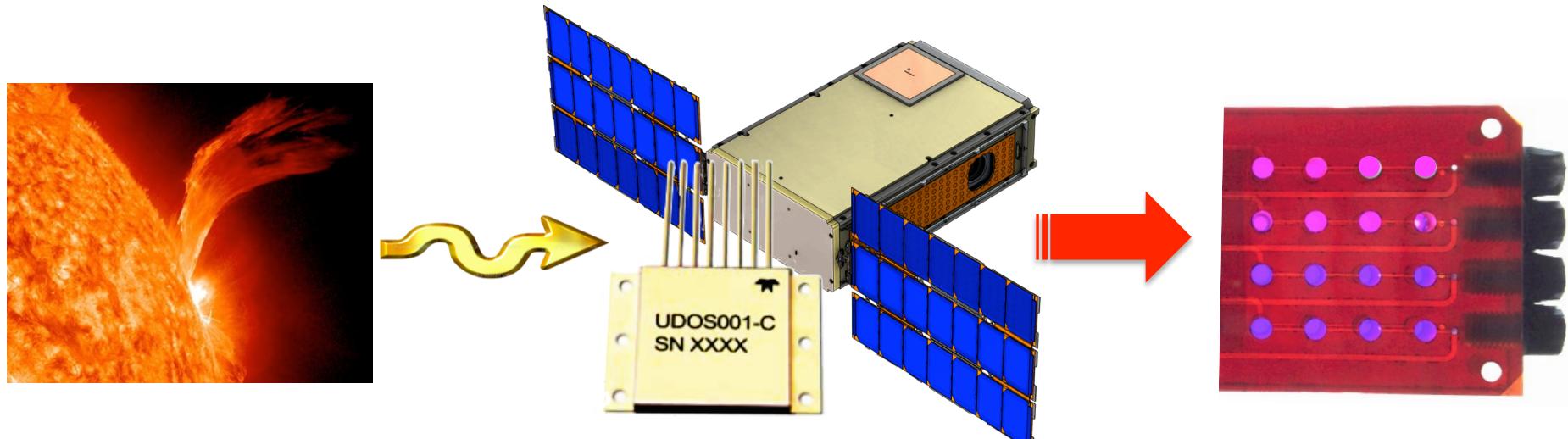




Payload Configuration (cont'd.)

• Solar Particle Event Autonomous Trigger

- Onboard monitor of TID (backups: TimePix shutter (integration) time, ground command)
- Ionizing EM radiation (gamma) precedes particles by ~ hours
 - SPE differentiable from smaller coronal mass ejections
- **Activate “designated SPE set” of 16 fluidic wells**
 - measure radiation biological damage under wet conditions
 - *expected to generate more damage wet than in dry state*



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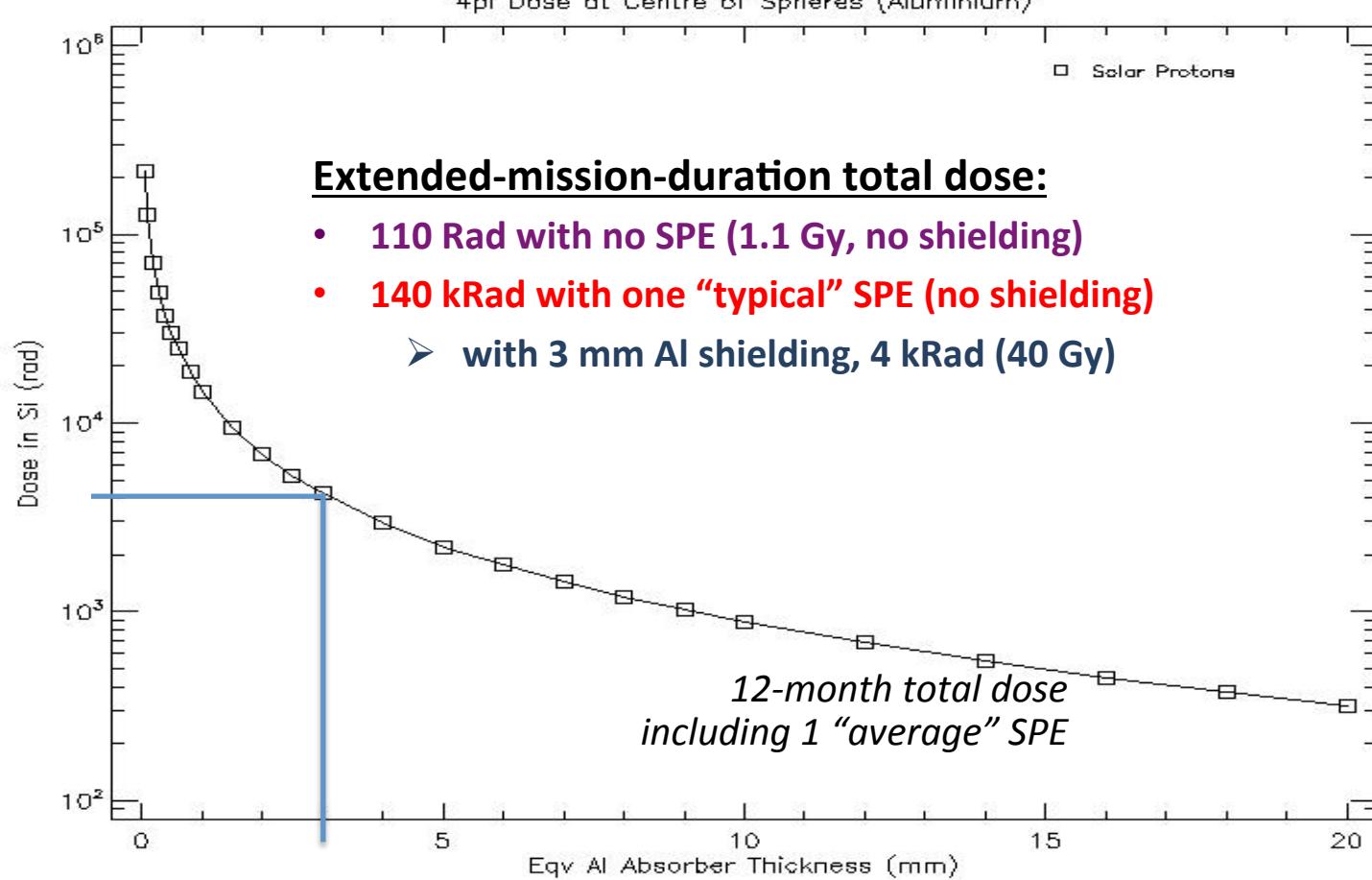


Radiation Environment for EM-1 Mission

Total Ionizing Dose (Si):

Ambient Flux + single Solar Particle Event

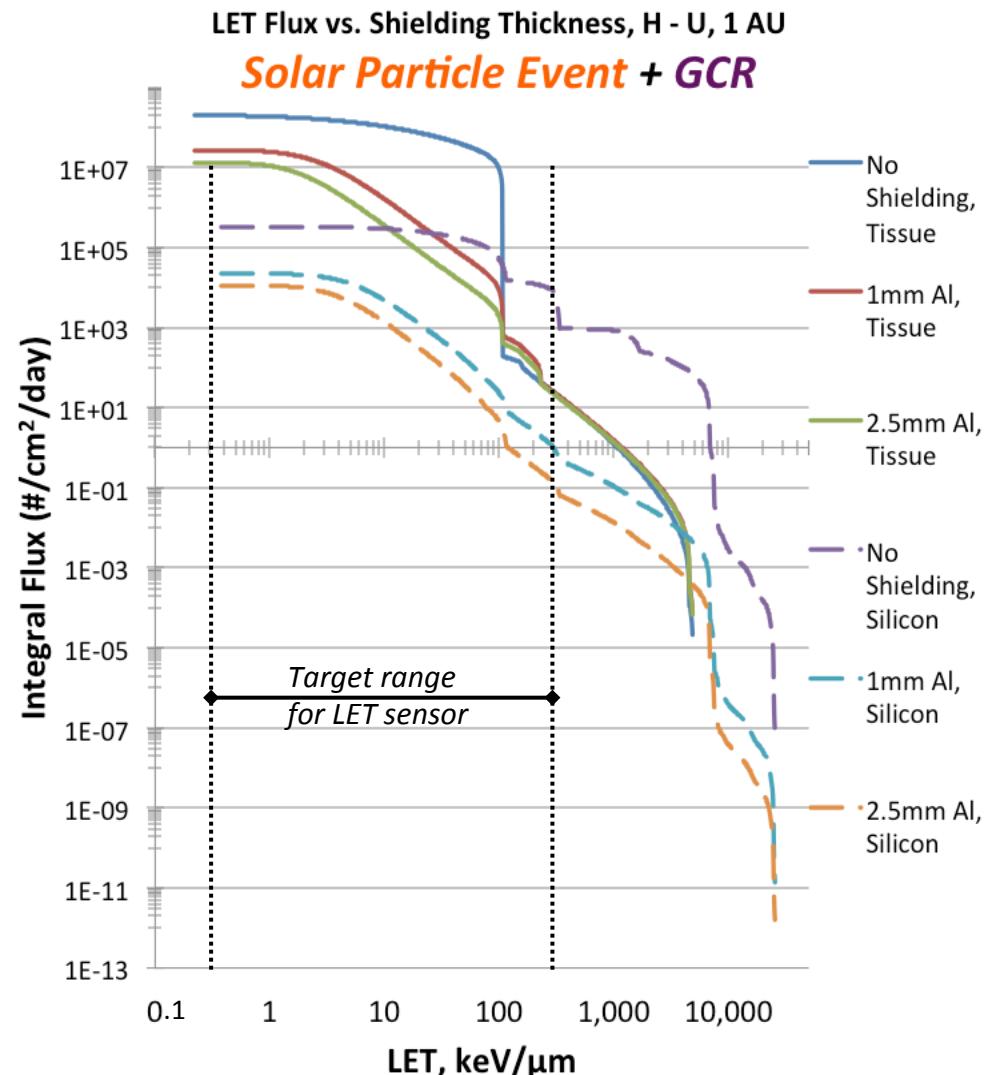
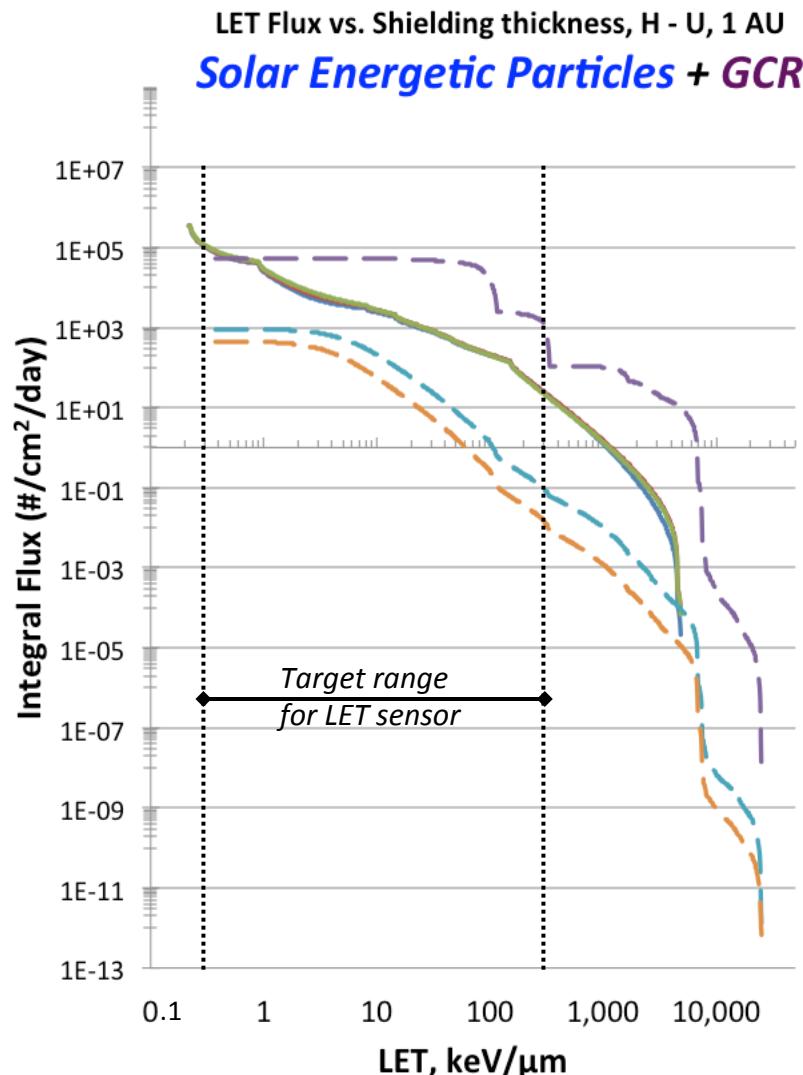
Model:
SHIELDOS
E-2Q





BioSentinel/Mars Instrument

Radiation Environment





Payload Heritage

- **GeneSat** – overall bio P/L integration; hermetic sealing (3 years)
- **PharmaSat** – optics, thermal, multi-well fluidics, *S. cerevisiae*, biocompatibility, 48 µwells
- **O/OREOS SESLO, SEVO payloads** – dried organisms, 12-mo. stasis; cell filters in optical path; thermally isolated “bioblocks”; spectral data cache-and-downlink; high-radiation survival:
 - > *3.5 years, high-inclination/high-altitude orbit*
- **EcAMSat** – multiple uniform multiwell fluid exchanges; 48 µwells
- **MisST** – image acquisition payload; peristaltic pump
- **SporeSat** – P/L processor w/ robust S/W
- **JSC RadWorks (CERN to ISS)** – LET spectrometer chip, control/ measurement system, S/W to extract radn. spectra
- **LRO** – Teledyne µDOS001
- **LADEE** – S/C avionics incl. S/W



Proposed LET Spectrometer Prelim. Requirements

Objective: Measure time-resolved LET of charged particles w/ solid-state device

- **Nominal LET range:** 0.2 to 300 keV/ μ m • 256 x 256 pixels, \geq 14 bit depth
- **Target species:** H-1, He-4, C-12, O-16, Mg-24, Si-28, Fe-56
- **Detector volume:** 14 mm x 14 mm x 0.3 mm
- **Integration ("shutter") time:** dynamic feedback, target frames \sim 3% full
- **Range of per-frame integration time:** 0.3 - 30 sec
- **Measurement duty cycle:** continuous over mission (up to 18 mo)
- **Power:** \leq 1.5 W total power in active mode; \leq 0.5 W dissipated on sensor chip
- **Voltage input:** 5-6 VDC
- **Size:** 1 cm x 2 cm x 6 cm up to 1 cm x 7 cm x 7 cm • **Mass:** \leq 0.25 kg
- **S/W:** converts each "frame" to a binned tally of radiation events:
 - **256 bins** cover 0.2 to 300 keV/ μ m; **bit depth:** 32; **bin width** \sim 3% of center LET
 - *All frames per hour co-binned to provide one 256-bin hourly "spectrum" of LET events for onboard storage, downlink*
- **Sensor to S/C Bus Communication:** ethernet or serial (RS-422 preferred)
- **Data generated:** \sim 9 MB/yr

Onboard processor may be available to host data processing